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Pushing the Envelope: Analyzing Building Envelope's Resiliency Using Future Climate Predictions and Rainfall Progressions

Yure Suarez and Frances Gooding

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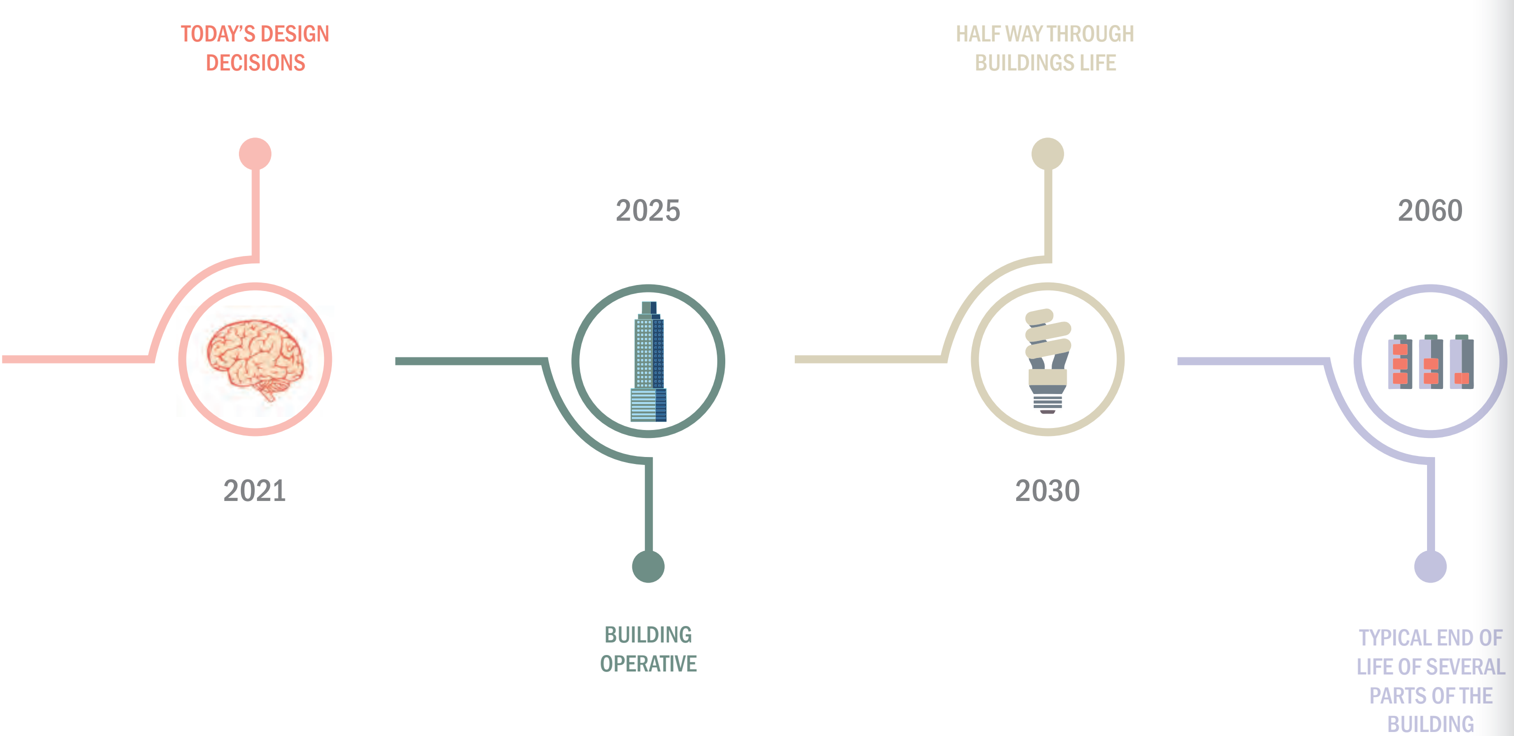
Background

As our understanding about climate change and future climate projections evolve, we get the opportunity to test the resiliency of our current design standards against such projections. **The decisions we make today create buildings that will be withstanding the weather conditions and events of the next 50 to 200 years.** We often tell clients we are designing them a 50-year building. As architects and designers, it is our responsibility to ensure the health, welfare, and safety of building occupants that will inhabit future conditions in our buildings. We need to do so without increasing opportunities for mold and corrosion within our buildings.



Timeline diagram. From Yure and Frances

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Emissions

The emissions from human influences affecting climate include heat-trapping gases such as carbon dioxide (CO_2), methane, and nitrous oxide, as well as particles such as black carbon (soot), which has a warming influence, and sulfates, which have an overall cooling influence. In addition to human-induced global climate change, local climate can also be affected by other human factors like heat islands and natural factors such as geographic variability. Scientists have reported their concern on the effects that these emissions are having in global temperatures.

Studies show that a trend of increasing extreme weather events and other weather-related phenomenon consistent with rising temperatures. These include increases in heavy precipitation nationwide, especially in the Midwest and Northeast; heat waves, especially in the West; and the intensity of Atlantic hurricanes. These trends are expected to continue, and although accurate prediction is unrealistic, our research aims at projecting and testing historical data.

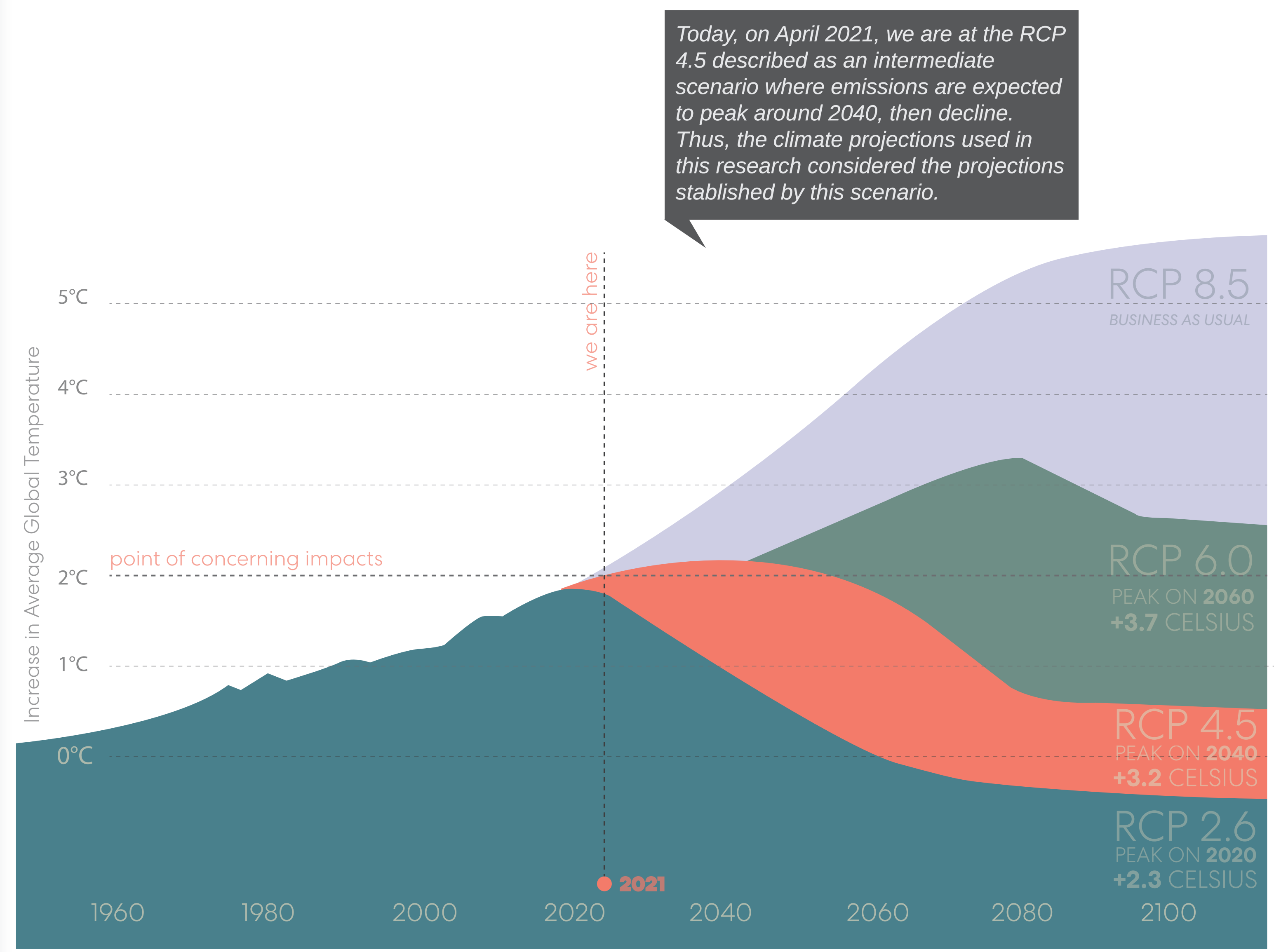


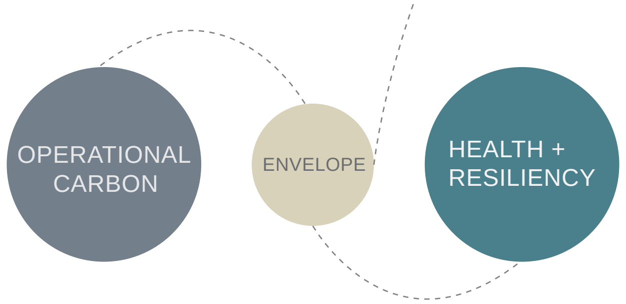
Diagram emissions IPCC adapted from Carbon Span Incubator. From Yure and Frances

The Big Idea

We started with a simple idea. Test a wall type with increased rain to simulate increased rain in 2060 to determine if a wall commonly used today will be resilient to anticipated temperature and rainfall rates of the future. We had planned to test one wall type in one location, but we received feedback on our initial submission that increasing the number of locations would have more value to the firm as a whole, rather than just our little neck of the woods.

When we started our project with great ambition, we intended to test three wall types in five climates, ranging from Zone 2 (Houston TX) through Zone 6 (Chicago IL). We included several cites that had special significance to us including Dallas TX, where we currently both live and Seattle WA, where Frances had lived before moving to Dallas.

We were going to play to our individual strengths, with Yure modifying the weather files and Frances analyzing the wall types in WUFI. Frances had already been investigating local wall types in WUFI for several years. Yure had no fears regarding diving into the crazy world of weather files in their modification.



Is our current wall type design going to be resilient?

Diagram by Yure and Frances

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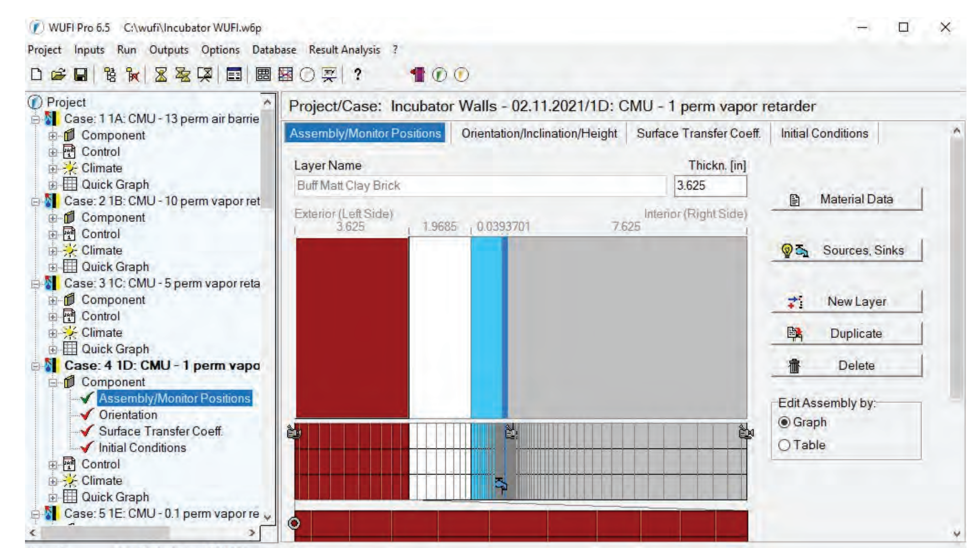
What is WUFI?

WUFI is an acronym for Wärme Und Feuchte Instationär—which, translated from German means heat and moisture transiency. The software, developed in a joint venture between the US and Germany, models the latest findings regarding vapor diffusion and moisture transport in building materials and assemblies. The software has been validated by detailed comparison with measurements obtained in the laboratory and empirical measurements of assemblies at Oak Ridge National Laboratory.

At Perkins&Will, we often utilize this software to optimize building envelope design. We use a methodology outlined in ANSI/ASHRAE Standard 160-2016 – Criteria for Moisture-Control Design Analysis in Buildings. Starting conditions, initial moisture content, and other parameters for setting up the modeling in WUFI are all covered by this standard. This standard also outlines failure conditions in a cavity wall, specifically mold growth and steel corrosion.

Modeling wall assemblies in WUFI



WUFI View. Screenshot by Yure and Frances

Wall Types Selected

We first selected wall assemblies based on previous research done by Joseph Lstiburek at Building Science Corporation. In his article BSD-106: Understanding Vapor Barriers, he provides 16 wall types that have been evaluated using dynamic hygrothermal modeling (WUFI). “The moisture content of building materials that comprise the building assemblies all remained below the equilibrium moisture content of the materials as specified in ASHRAE 160 P under this evaluation approa. More significantly, each of the recommended building assemblies have been found by the author to provide satisfactory performance under the limitations noted. Satisfactory performance is defined as no moisture problems reported or observed over at least a 10-year period.” From there, we narrowed the assemblies down to ones that were applicable in all hygrothermal regions.

From these previously vetted walls, we chose two wall types that are commonly used in our K-12 practice, as this is Frances’s background. In her experience, these assemblies are used in the Midwest, the Pacific Northwest, and in North Texas with changes only in the air barrier/vapor retarder for differing climates. Wall assemblies and material callouts for these wall types are shown.

Both partitions are applicable to all hygro-thermal regions

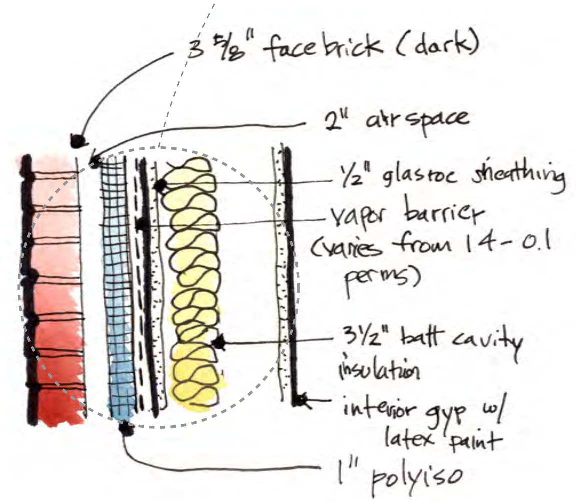


Diagram CMFM - Concrete Block with Exterior Insulation and Brick or Stone Veneer.

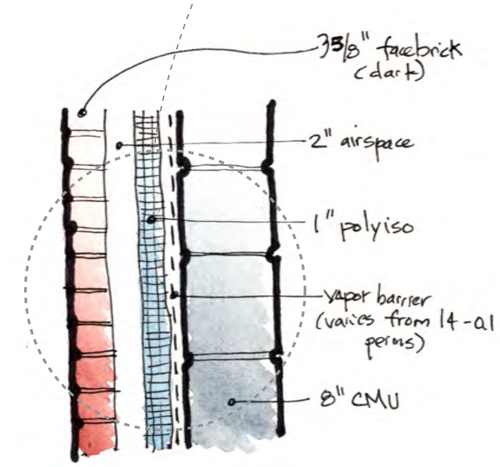


Diagram CMU - Concrete Block with Exterior Insulation and Brick or Stone Veneer. By Yure and Frances

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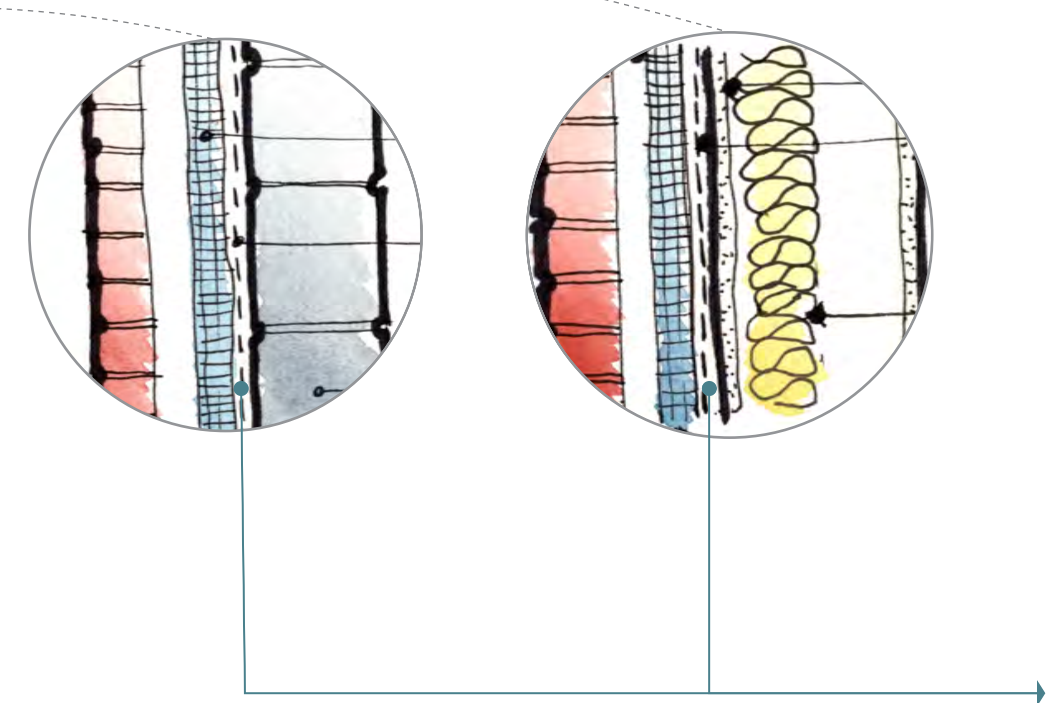
Fine Tuning the Vapor Retarder in the Assembly

One of the things that got Frances interested in studying assemblies in WUFI was her move to Texas. She had always used vapor retarders in her assemblies when practicing in Ohio, Kentucky, and Washington State. However, much to her surprise the common assemblies in Texas had no vapor retarder and only had an air barrier. The vapor transmission through this specific air barrier measures at 14 perms, high enough for it to be called “vapor permeable.”

Our initial hypothesis was that by adding more heat and more rain, we would also be increasing the amount of moisture in the air, and that at some point the wall would require a vapor barrier. So from our base case of two different walls with a 14 perm air barrier, we began to decrease the permeability of the barrier to 10 perms (still vapor permeable) all the way down to 0.1 perms (vapor impermeable) with stops at vapor semi-permeable (5 perms) and vapor semi-impermeable (1.0 perms).



14 PERM
10 PERM
5 PERM
1 PERM
0.1 PERM

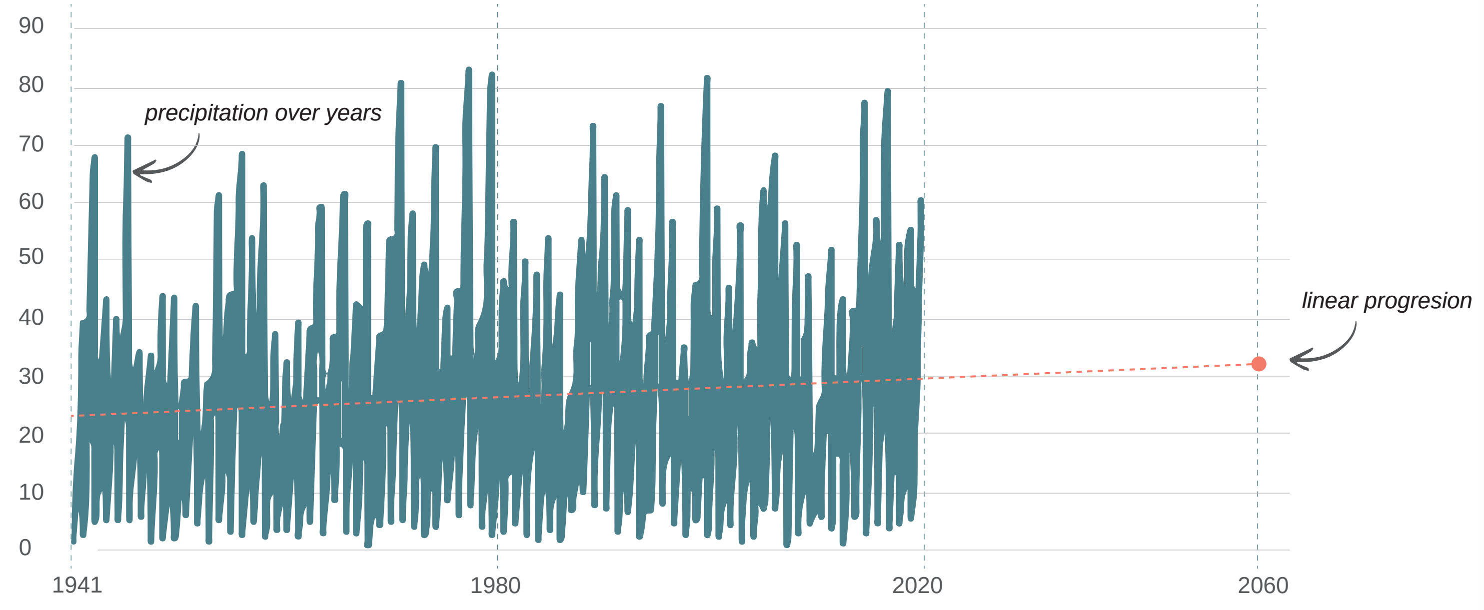
Fine Tunning Vapor Retarder Close Up. By Yure and Frances

Methodology for weather files

Currently there are many different sites where you can obtain morphed weather files that reflect the different Representative Concentration Pathways (RCP) set forth by the Intergovernmental Panel in Climate Change (IPCC). An RCP is a greenhouse gas concentration trajectory adopted by the IPCC to illustrate four climate pathways. The four pathways describe different climate futures depending on the volume of greenhouse gases emitted in the years to come. Unfortunately, weather files typically available only reflect the temperature projection and do not contain changes to precipitation.

Climate change affects more than just temperature. The location, timing, and amount of precipitation will also change as temperatures rises. Thus, a critical part of this research was the integration of morphed precipitation data into the weather files. The process planned for this project was using historical data and forecast in excel using linear regression. A linear regression plots points along two axes, x and y, and finds a line that represents the pattern seen. In this case, x is time (years) and y is precipitation. When plotting this line through known data points from the past and present, we can make predictions on future precipitation as temperature changes. The idea was to recollect a sample of historical data and observe the behavior of the line of the average historical trend. We knew that for most cases in the USA this line was going to have a positive slope, meaning as temperature increase, precipitation also increase.

The largest constraint we experienced with the weather files was the carying completeness of the precipitation data. We used data from both the National Oceanic and Atmospheric Administration (NOAA) and Energy Plus, funded by the US Department of Energy, as these were the most complete files we observed. However, we found that even these files did not have complete data for all 8760 hours in the year. Additionally, each year had different inconsistencies, such as the amount of data found in the file.



Precipitation Data from 1941 to 2020 with linear progresion to 2060

Thus, even though we were able to see averages and trends from a projected precipitation increase, we were not able to use the data to create a file that was readable by WUFI reflecting a complete years' worth of data. In consequence, we were unable to complete this portion of our research. Undeterred, we purchased the files from Weather Shift, a trusted source that Perkins&Will have used in the past.

On the positive side, the model used by Weather Shift is much more refined than the methodology we had originally proposed. We purchased a 2060 morphed file with a 4.5 RCP 50% with morphed precipitation. Weather Shift uses a model called Mean Absolute Deviation (MAD) that besides forecasting it evaluated the model for errors and verify the model results. The resources link to their research papers in this topic can be found in our resources section for further references.

While we didn’t use our original computations for modeling the weather, we did compare it to the morphed files from Weather Shift. We found that the results for certain months are similar, but the limitation of using the Linear Regression is that it does not reflects the seasonal behavior of rain. Our data showed a constant increase rather than the cyclic behavior of seasons.

Precipitation Data from Weather Shift. Hitoric vs. Future

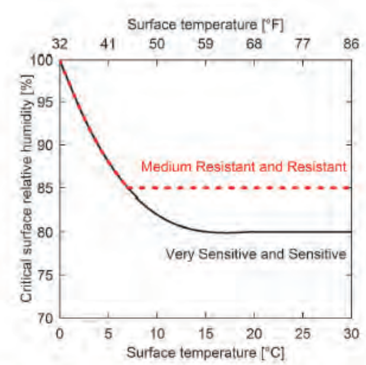
The Test

Finally, we were ready to begin testing our assemblies in WUFI. Altogether, we ran simulations on 20 assemblies.

2 assemblies x 5 different vapor barriers X two different weather conditions (lets make this a graphic)

Failure Conditions

In order to evaluate the results, we developed failure conditions for both the CFMF and CMU assemblies. As indicated previously, for cavity walls, failure condition is the growth of mold in the assembly. These failure conditions applied to 10 of our wall assemblies. This specific failure condition is indicated by the graph below, also taken from ASHRAE 160.



Critical surface relative humidity as a fuction of surface temperature for different material sensitivity classes. Diagram from ASHRAE Standard 160-2016.

2x 5x 2x = 20

ASSEMBLIES	VAPOR BARRIER	WEATHER	SIMULATIONS
CFMF CMU	14 PERM 10 PERM 5 PERM 1 PERM 0.1 PERM	CURRENT FUTURE	

Variables and extent of study. Created by Yure and Frances

Assuming we avoid the use of wood, wood materials and paper faced objects in our wall assembly, as we have done, our materials fall into the medium resistant category as indicated by the red line in the graph. For temperatures above 44.6 degrees Fahrenheit, the surface RH on critical surfaces must remain below 85% RH. Below 44.5 degrees, the graph above shows a curve indicated by the following equation:

$$RH_{crit} = \begin{cases} -0.0004578T_s^3 + 0.09333T_s^2 - 6.306T_s + 221.21 \\ \quad \text{when } T_s \leq 44.6°\text{F}, \\ 85 \text{ when } T_s > 44.6°\text{F} \quad [T_s \text{ in } °\text{F}] \end{cases}$$

Fortunately for our research, Tyrone Marshall, a Senior Computational Designer in Perkins&Will's Research Lab, has translated these difficult equations into an excel spreadsheet.

CMU Wall Failure Conditions

Unfortunately, we didn't have an ASHRAE standard for evaluating the failure conditions in our CMU walls. Our review of the current literature turned up very little for failure of CMU walls due to moisture. One of the characteristics of CMU is that it can store large amounts of water within and not fail, so the fact there isn't a lot of research on the subject makes plenty of sense.

We did find one article, written by Zenith Czora, Che, ATSC, a research and product development chemist that indicated that one CMU failure that is related to moisture is paint adhesion. Above a certain percent moisture, paint will fail to adhere to the CMU wall. He indicated that in New Zealand, concrete and CMU above 5.5% moisture would lead to lack of adhesion. Looking for a second source for this percentage, we turned to our own typical specifications for Texas. Specification Section 09 91 00 – PAINTING limits the percent moisture in masonry products to 12% when measured by a moisture meter.

From this we have developed a failure condition for CMU as follows:

$$\% = \frac{\text{(water content in lbs/CF)}}{\text{(normal weight CMU in lbs/CF)}} = \frac{\text{(water content in lbs/CF)}}{\text{(normal weight CMU in lbs/CF)}}$$

% > 12% = failure condition

Our Results for Cavity Wall Assemblies

We got some very unspectacular results for our analysis of brick on CFMF with a cavity. We found no failures in the assembly for any of the 10 conditions tested. The differences in the results are so similar that we believe they're essential the same in the Houston climate, now or with future weather files. The only metric that we analyzed that had any change was the percent moisture difference between stabilized initial conditions, two years after the assembly is in place, and result conditions, five years after the assembly is in place. In all cases, the percent change is negative, indicating that the wall assembly is still drying out, albeit minimally, many years later.

Again, these differences are very small, likely within the margin of error in a study with so many variables. No generalized trend can be decerned.

To summarize our findings for the CFMF/cavity wall assembly, we have discovered that this wall types is VERY RESILIENT, to anticipated increases in temperature and rainfall due to global climate change. It also appears that any mistakes during construction resulting in a less permeable vapor retarder layer will not create failures within the assembly, now or 40 years in the future. Our general rule of thumb to use an air barrier in lieu of a vapor barrier in hot moist climates, appears to hold true.

These walls type are VERY RESILIENT

Wall Type No.	Weather Year	Permeability of Vapor Barrier	Failure (Y/N)	% Difference Cavity Moisture Content
1A	2020	14.0	N	-0.06%
1A	2060	14.0	N	-0.05%
2B	2020	10.0	N	-0.06%
2B	2060	10.0	N	-0.05%
2C	2020	5.0	N	-0.05%
2C	2060	5.0	N	-0.05%
2D	2020	1.0	N	-0.06%
2D	2060	1.0	N	-0.06%
2E	2020	0.1	N	-0.07%
2E	2060	0.1	N	-0.08%

Chart of Results from WUFI - Cavity Wall

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Our Results for CMU Wall Assemblies

Our results for the CMU wall weren't much more spectacular. Again, we found no failures in the assembly for any of the 10 conditions tested. All results followed the same general curve of continuing to dry and reducing the percent moisture in the interior face of the CMU over time.

Percent moisture never got close to the 12% we have previously discussed as a failure condition. Minimum and maximum water content for each assembly is indicated below.

Wall Type No.	Weather Year	Permeability of Vapor Barrier	Failure (Y/N)	% Difference Cavity Moisture Content
1A	2020	14.0	N	2.217%
1A	2060	14.0	N	2.217%
2B	2020	10.0	N	2.217%
2B	2060	10.0	N	2.217%
2C	2020	5.0	N	2.217%
2C	2060	5.0	N	2.217%
2D	2020	1.0	N	2.217%
2D	2060	1.0	N	2.217%
2E	2020	0.1	N	2.217%
2E	2060	0.1	N	2.217%

Chart of Results from WUFI - CMU Wall

We were surprised at first that the water content is the same for every assembly, but upon further thought, the results make sense. The interior face of the CMU is more dependent on the interior conditions, rather than exterior conditions. As the interior conditions remain unchanged, the water content of the CMU would also remain the same.

Again, for the CMU wall assembly, we have discovered that this wall type is VERY RESILIENT, to anticipated increases in temperature and rainfall due to global climate change. It also appears that any mistakes during construction resulting in a less permeable vapor retarder layer will not create failures within the assembly, now or 40 years in the future. Our general rule of thumb to use an air barrier in lieu of a vapor barrier in hot moist climates, appears to hold true.

Percent Water in CMU (interior face). By Tyrone's spreadsheet

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Next Step

All results we received were for one location in the United States, Houston TX with a clear hot-humid climate. We would love to continue with this same methodology in many other climate zones. Specifically, we would like to look at climates MIXED temperature range, where the warm side of the wall flips with the seasons, both MIXED-HUMID and MIXED-DRY. We anticipate that much more variable conditions within the wall, combined with the increased temperature and rainfall of global climate change, would provide more variable results.

Once more climate zones are tested using the methodology we have established, the results will help us understand and mitigate possible repercussions that the change of the climate may have in the envelope design. The remaining 5 climate zones that we originally had selected would require an additional fee of $2,250 in weather files, 10 hours of modeling, and 20 additional hours for analysis and recommended changes to these assemblies. After this experience, we both agree that this is the first time we would be eager to see failure conditions in our wall assemblies.

While not as applicable to our practice, this research has also piqued our interest in failure conditions related to moisture and paint adherence to CMU. We can easily image a more empirical study that dials in the exact moisture content leading to failure following installation. We can find no published research of this nature, and assume our current specifications reflect predominant manufacturers' literature. It's unclear if the manufacturers' literature relies on a rule of thumb or an actual test.

Proposed next steps

2x	5x	5x	=	50
ASSEMBLIES	VAPOR BARRIER	WEATHER		SIMULATIONS +
TBD (per climate)	14 PERM 10 PERM 5 PERM 1 PERM 0.1 PERM	CURRENT FUTURE		

Variables for next study. Created by Yure and Frances

Resources

Weather/precipitation data:

Station names: https://www.nws.noaa.gov/mdl/synop/stadrg.php

Haywood Plots: https://www.ncdc.noaa.gov/cag/city/haywood/USW00012918/pcp/12

NOAA hourly precipitation data: https://catalog.data.gov/dataset/u-s-hourly-precipitation-data

Past Weather by Zip Code: https://www.climate.gov/maps-data/dataset/past-weather-zip-code-data-table

Iowa Univ: https://mesonet.agron.iastate.edu/request/asos/hourlyprecip.phtml?network=TX_ASOS

Hourly Data: https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly

Data Analysis:

Linear Regression: https://blog.clearbrain.com/posts/how-to-predict-any-value-using-linear-regression#:~:text=One%20of%20the%20most%20common%20Supervised%20Learning%20approaches%20to%20predicting,you%20are%20trying%20to%20predict.

Forecast in excel: https://www.absentdata.com/excel/excel-forecasting/

Morphed weather files:

Weather Shift: https://www.weathershift.com/library

Weather shift tools: https://www.weathershift.com/WeatherShift%20Water%20Tools.pdf

Paper on morphing rain https://iopscience.iop.org/article/10.1088/1757-899X/407/1/012154/pdf

Selection of wall types for modeling: https://www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers

WUFI modeling resources:

WUFI Forum, Materials: https://www.wufi-forum.com/viewforum.php?f=3

CFMF Failure conditions: ANSI/ASHRAE Standard 160-2016 – Criteria for Moisture-Control Design Analysis in Buildings

CMU Failure Conditions:

https://www.linkedin.com/pulse/moisture-cmus-when-safe-paint-zenith-czora-che-atsc/